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B70 09086

SUBJECT: Required Artificial G Field for the Skylab Gravity Substitute Workbench - Case 620

DATE: September 30, 1970

FROM: W. W. Hough

ABSTRACT

Expected rigid body motion of the Skylab determines minimum requirements on the artificial gravity field produced by the experimental gravity substitute workbench. If the artificial gravity field is greater than 10^{-4} g's, no operational difficulties due to predictable vehicle dynamics are expected. Crew and equipment induced vibrations of the workbench surface could cause difficulties, but the significance of these can probably best be answered by trying the workbench in space.

(NASA-CR-113891) REQUIRED ARTIFICIAL G FIELD FOR THE SKYLAB GRAVITY SUBSTITUTE WORKBENCH (Bellcomm, Inc.) 9 p

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MEMORANDUM FOR FILE

INTRODUCTION

The purpose of this memorandum is to specify the minimum requirement on the artificial gravity field produced by the gravity substitute workbench currently included as an experiment (M507) in the Skylab Program. The physical requirement is that an object placed on the surface of the bench will remain there in the presence of the known dynamic environment. Included in this environment are planned vehicle attitude maneuvers and accelerations due to TACS thruster firings. This environment is known and the effect at the workbench surface can be analyzed to specify minimum requirements on the artificial gravity field. There are other possible disturbances, such as crew and equipment induced vibrations, but the effects of these are difficult to impossible to analyze, and they are only briefly discussed.

ACCELERATION OF THE WORKBENCH SURFACE

The location of the gravity substitute workbench in the crew quarters of the Workshop is shown in Figure 1. The accessible side of the bench is toward the Skylab center of mass. Dimensions are given in a centroidal u, v, w system which can, for the purposes of this discussion, be considered axes of principal moments of inertia. The u axis is rotated from Skylab x by about 4°, which is the principal axis offset caused by the ATM. The acceleration of the surface of the workbench (not necessarily of something on it) is

$$\underline{A}_{wb} = \underline{A}_{cg} + \dot{\underline{\Omega}} \times \underline{r}_{wb} + \underline{\Omega} \times \underline{\Omega} \times \underline{r}_{wb} \tag{1}$$

where $\underline{A}_{cg}$ is the linear acceleration of the Skylab center of mass, $\underline{\Omega}$ is the Skylab angular velocity, $\dot{\underline{\Omega}}$ is its angular acceleration, and $\underline{r}_{wb}$ is the position vector of the workbench. The additional terms in the more general expression for acceleration of a particle in a moving reference frame involve linear velocity and acceleration relative to the frame, and here the workbench is assumed fixed to the vehicle. Study of vibration of the surface would involve the relative acceleration term.

Workbench acceleration in the normal direction, A_{wbn} (4° from u), will add to the artificial gravity field if it is forward (toward +u) as a normal force must develop to accelerate an object resting on the bench with the bench. If normal acceleration is aft, it will subtract from the artificial g field as the bench will be accelerating away from the object. Transverse acceleration of the bench, A_{wbt}, will cause it to slip out from under the object if this acceleration times the mass of the object is greater than the static friction force that can develop. The maximum static friction force is the normal force, N, times the coefficient of static friction, μ_s. Thus for no relative lateral motion between the workbench and the object,

$$N\mu_s = M A_N\mu_s \geq MA_{wbt}$$

or

$$A_N \geq A_{wbt}/\mu_s \tag{2}$$

where A_N is the magnitude of the artificial gravitational field plus forward normal acceleration of the workbench.

ROTATIONAL MANEUVERS

A typical attitude maneuver for Skylab is a constant rate rotation from the solar inertial attitude to the local vertical attitude for earth resources experimentation, and a typical constant angular velocity vector expressed in the u, v, w system is

$$\underline{\Omega} = \begin{Bmatrix} -0.57 \\ -1.33 \\ 0.36 \end{Bmatrix} \times 10^{-3} \text{ rad/sec}$$

Noting from Figure 1 that the position vector of the Workbench is

$$\underline{r}_{wb} = \begin{Bmatrix} -31 \\ 0 \\ -5 \end{Bmatrix} \text{ feet}$$

the acceleration is found from the last term of (1)

$$\underline{A}_{wb} = \underline{\Omega} \times \underline{\Omega} \times \underline{r}_{wb} = \begin{Bmatrix} 60 \\ -21 \\ 17 \end{Bmatrix} \times 10^{-6} \text{ ft/sec}^2$$

After a little trigonometric manipulation, we find that the acceleration of the workbench normal to its surface, about 2×10^{-6} g, is almost twice the tangential acceleration. The coefficient of static friction between the object and the bench would have to be less than .5 for the object to slide off the bench even if the bench produced no artificial g field. As the artificially induced field is expected to be magnitudes larger than 10^{-6} g, practically no friction is required to keep the object from sliding. The constant rate rotation is simply not a problem.

TACS THRUSTER FIRING

Because the angular velocity induced by a TACS thruster firing a) helps keep objects on the workbench, b) is almost insignificant, the acceleration of the bench due to a firing is calculated without considering the last term of (1). The result is equivalent to the instantaneous acceleration with the vehicle initially at rest. When the force $\underline{F}$ is suddenly applied by operation of TACS thruster, Skylab will accelerate both linearly and angularly. Newton's law gives us

$$\underline{A}_{cg} = \underline{F}/M$$

Euler's equations in principal coordinates are uncoupled due to the absence of angular velocity components, and thus the components of $\dot{\underline{\Omega}}$ are

$$\dot{\Omega}_i = T_i/I_i$$

where T_i are the components of

$$\underline{T} = \underline{r}_F \times \underline{F}$$

The TACS thruster shown in Figure 1 with position vector

$$\underline{r}_F = \begin{Bmatrix} -40 \\ 0 \\ -10 \end{Bmatrix} \text{ feet}$$

will produce the maximum acceleration at the beginning of the mission when the TACS is fully pressurized. At that time

$$\underline{F} = \begin{Bmatrix} 0 \\ 100 \\ 0 \end{Bmatrix} \text{ lbs.}$$

The required mass properties are

$$M = 5600 \text{ slugs}$$

$$I_u = 0.66 \times 10^6 \text{ slug ft}^2$$

$$I_v = I_w = 4.2 \times 10^6 \text{ slug ft}^2$$

Using the above formulas to evaluate the first two terms of (1), we find that the instantaneous workbench acceleration is

$$\underline{A}_{wb} = \begin{Bmatrix} 0 \\ 60 \\ 0 \end{Bmatrix} \times 10^{-3} \text{ ft/sec}^2 \approx \begin{Bmatrix} 0 \\ 2 \\ 0 \end{Bmatrix} \times 10^{-3} \text{ g's.}$$

The acceleration is purely tangential, so $A_{wbt} = 2 \times 10^{-3}$ g's. Coefficients of static friction for typical plastic and metal to metal interfaces range from 0.4 to 1. Therefore, from (2),

$$A_N \geq (2\text{-}5) * 10^{-3} \text{ g's}$$

for no sliding to occur between the bench and metal or plastic objects resting on it.

If A_N is less than the above value $(f(\mu_s))$, the object will slide on the workbench when the TACS thruster shown in Figure 1 is fired--but not very far. Under normal circumstances, the thrusters will be operated only in a minimum impulse mode, and the minimum impulse is set at 4 lb sec. When the thrust of a TACS thruster is 100 lbs, the firing time is thus .04 sec. The maximum possible slip is then

$$d = 1/2\ A_{wbt}\ t^2 = 5 \times 10^{-5} \text{ feet },$$

the actual slip will be less as sliding friction will accelerate the object, but at a lesser rate than the workbench.

As the mission progresses, the system pressure and therefore the thrust of a TACS thruster decreases, but the minimum impulse remains constant. The maximum slip distance increases and would reach 5×10^{-4} feet when the thrust is 10 pounds. The artificial g field would have to be ten times weaker for slip to occur, however.

<u>TORQUEING BY CMG's</u>

The ATM Control Moment Gyros can apply an average torque for a period close to a minute that is comparable in magnitude to the torque applied by a 10 lb TACS thruster. The maximum average torque for a 12000 ft lb sec change in angular momentum is approximately 270 ft lb. If applied about the w axis

$$\underline{T} = \begin{Bmatrix} 0 \\ 0 \\ -270 \end{Bmatrix} \text{ ft lb}$$

and

$$\underline{\dot{\Omega}} = \begin{Bmatrix} 0 \\ 0 \\ -46 \end{Bmatrix} \times 10^{-6} \text{ rad/sec}^2.$$

The average acceleration of the workbench is then

$$\underline{A}_{wb} = \begin{Bmatrix} 0 \\ 2.1 \\ 0 \end{Bmatrix} \times 10^{-3} \text{ ft/sec}^2 = \begin{Bmatrix} 0 \\ 6.5 \\ 0 \end{Bmatrix} \times 10^{-5} \text{ g's.}$$

An object could slip off the workbench (1 foot in 30 seconds) if the artificial g field

$$A_N < (6.5 \times 10^{-5} - 1.6 \times 10^{-4}) g's,$$

but predictions of the artificial gravity field for both the aerodynamic and electrostatic workbenches are above 10^{-4} g's.

CONCLUSIONS

Rigid body vehicle accelerations analyzed here will not cause difficulty in the operation of the experimental gravity substitute workbench if the artificial gravity field is greater than 10^{-4} g's. Although a minimum-impulse TACS thruster firing might cause an object to slide relative to the bench, the slip distance is too small to notice. Rigid body vehicle accelerations induced by crew motion are, at worst, two orders of magnitude less than those induced by a TACS thruster firing, or a third those induced by CMG torquing, and are not a problem.

There are possible vibration effects that could cause difficulty, but are not subjects of easy analyses. Forced transverse vibration of the workbench surface due to local excitation by the operating crewman might cause objects to hop about on the surface, not unlike skip of a finely balanced tone arm of a victrola due to people walking in its vicinity. In the aerodynamic bench, oscillations induced by the fan and motor, or flutter of the wire screen in the high-speed air stream might cause difficulties. The significance of these possible vibration effects can probably best be answered by trying the workbench in space.

1022-WWH-jf

William W. Hough

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Attachment

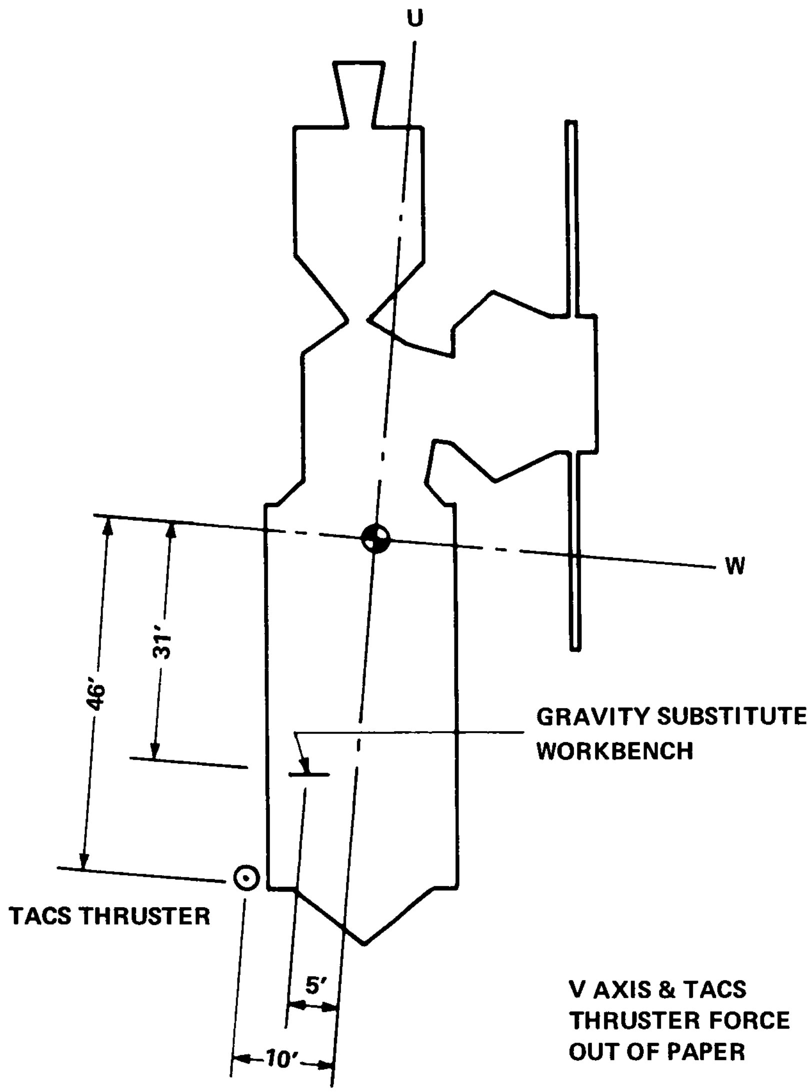

FIGURE 1 - GRAVITY SUBSTITUTE WORKBENCH LOCATION IN SKYLAB PRINCIPAL COORDINATES

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